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# Effects of Irrigation on Growth Traits, Nutritional Quality and Seed Characteristics of *Medicago falcata* var. *Romanica* in an Oasis

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## Abstract

The present study explored the effects of irrigation and growing year on the growth traits, nutritional quality and seed characteristics of Roman alfalfa. The study was comprised of three irrigation regimes and three growth years from 2016–2018 in Xinjiang, China. Results showed that the plant height, branch number, stem-leaf ratio, stem diameter and dry matter per plant of Roman alfalfa increased gradually with increasing irrigation amount, the stem-leaf ratio, hay yield and crude protein content in the $D_{125}$ and $D_{100}$ treatments were significantly greater than in the $D_{75}$ treatment ($P < 0.05$). Of all the growth factors, plant height contributed the most to hay yield, and stem-leaf ratio contributed the most to crude protein content. Compared to wild species, these growth attributes of cultivated Roman alfalfa increased with each growth year. The dry matter weight per plant of Roman alfalfa increased by 26.89 and 37.74% in the sec year and the third year, respectively, compared to first sowing year. The content of crude protein in the sec and third years was significantly higher than first year in wild species ($P < 0.05$). The 100-grain weight of wild species was significantly higher than cultivated alfalfa in the first year ($P < 0.05$), and decreased gradually with each growth year. In conclusion, compared with the effects of the growth year treatments, irrigation can significantly improve the growth traits and nutritional quality of Roman alfalfa. 

**Key word:** Roman alfalfa; Growth traits; Nutritional quality; Irrigation; Oasis

## Introduction

Roman alfalfa (*Medicago falcata* var. *Romanica* (Prod.) is a type of wild sickle alfalfa (*Medicago falcata*) and perennial leguminous forage with high crude protein content (Cui 1992). Because of its slender stem, large quantity, abundant leaves and high crude protein content, it has been considered that mown alfalfa can be used as a high-quality forage for livestock in its green and dry-yellow stages (Yu 2010; Cao *et al*. 2016). Roman alfalfa is mainly distributed on the northern slope of the western part of Balruk in Tacheng, Xinjiang, and on the gentle sunny slopes of low mountains and hills at 1200 m elevation (Yu 2010). One of the outstanding characteristics of this habitat is prevalence of many kinds of fine leguminous forage in the grassland with high occurrence frequencies, wide distributions and large proportions. The climate of Xinjiang is a typical continental arid climate, especially in the Tae Basin in the west of Junggar Basin, where the climate is dry, low natural rainfall, and limited grassland water resources (Yu *et al*. 1999). Therefore, it is of great significance for the development of high-quality leguminous forage, and the adjustment of the agricultural and animal husbandry industrial structure to study the growth characteristics and nutritional quality of alfalfa in the oasis area.

Water is an important factor affecting the growth and development of alfalfa plants, hay yield formation and nutritional value (Altinok *et al*. 2015; Rahmana *et al*. 2016; Zhang *et al*. 2016). Irrigation, as one of the important management measures in agricultural production, not only effectively regulates soil moisture content but also significantly improves the hay yield of artificial grassland (Sun *et al*. 2008; Zhang *et al*. 2015). The growth rate of stems and leaves of alfalfa slowed significantly, hay yield sharply declined, and nutrient quality decreased under drought stress (Fiasconaro *et al*. 2012; Wang *et al*. 2012). However, under sufficient irrigation conditions, the plant height and stem node number of alfalfa plants increased, the photosynthesis efficiency of leaves significantly increased, and the nutrient quality improved (Tao *et al*. 2015; Li *et al*. 2018). Other studies found that the hay yield of alfalfa increased gradually with increasing irrigation amount (Wang *et al*. 2015; Zhang *et al*. 2017; Wen *et al*. 2018). Therefore, a suitable irrigation amount can significantly improve the production performance and nutritional quality of alfalfa.

Drip irrigation technology has many advantages, such as saving water, increasing yield and improving quality (Zhang *et al*. 2008). In recent years, it has been widely applied in agricultural crops, such as cotton (Min *et al*.

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2016), corn (Liu *et al*. 2018), wheat (Lv *et al*. 2019), rice (Rao *et al*. 2018) and tomato (Du *et al*. 2017). Results show that drip irrigation could save 40~50% water and increase yield by 20~30% compared with traditional flooding irrigation (Zhang *et al*. 2008). In 2008, in 148 fields of Shihezi city, Xinjiang, drip irrigation technology was successfully applied to alfalfa field production for the first time and widely planted. A study showed that the total water use efficiency of alfalfa under drip irrigation increased by 42~44% compared with under flood irrigation (Zhang *et al*. 2015). The present study investigated whether drip irrigation technology can be applied to the field production of Roman alfalfa in an oasis region. At present, little research has been conducted on Roman alfalfa, and the research focuses mainly on the dormancy characteristics of Roman alfalfa seeds and the transmission of seeds in the digestive tract of sheep (Narkes 2016). However, few studies have reported on the characteristics of Roman alfalfa in oasis areas and effects of irrigation on its growth characteristics and nutritional quality. At the same time, especially under drip irrigation conditions, there is almost no research on the effects of different irrigation amounts on the production performance of Roman alfalfa.

Therefore, different irrigation gradients and planting years were set up to determine the growth characteristics and nutritional quality indexes of Roman alfalfa under drip irrigation in oasis areas in order to provide a theoretical basis its adaptation in oasis areas, the development of high-quality leguminous forage and the high-yield cultivation.

## Materials and Methods

### Experimental materials

Seeds of wild Roman alfalfa were collected from low mountains and gentle sunny slopes of the Barruk Mountains in Yumin County, Tacheng district, Xinjiang, China. Brown or black-brown Roman alfalfa pods were collected under natural growth conditions and brought back to the laboratory in cloth bags. Seeds were dried in a cool and ventilated place. Roman alfalfa pods were removed and stored in dry brown glass bottles. At the same time, 30 Roman alfalfa plants at the initial flowering stage (5~10% flowering) were collected and returned to the laboratory for the determination of stem-leaf ratio and nutritional quality.

### Experimental design

**Site description:** The experiment was conducted in the experimental field of Shihezi Tianye Group Agricultural Demonstration Park (44 26 N, 85 95 E) from 2016 to 2018. The soil type was grey desert soil. The 0~20 cm topsoil contains 25.5 $g{\cdot}kg^{-1}$ organic matter, 60.8 $mg{\cdot}kg^{-1}$ alkali-hydrolysed nitrogen, 25.5 $mg{\cdot}kg^{-1}$ available phosphorus and 330.2 $mg{\cdot}kg^{-1}$ available potassium. The soil bulk density was 1.56 $g{\cdot}cm^{-3}$, the saturated volumetric water content of 30.1%, and the field water holding capacity of 24.9%.

Roman alfalfa was sown on April 17, 2016, using drill method with a sowing depth of 1.0~1.5 cm, row spacing of 30 cm, and seed rate of 12 $kg{\cdot}ha^{-1}$ in plots with an area of 5.0 m × 7.0 m. A walkway of 1.0 m wide between the plots was left to prevent water infiltration between the plots. The drip irrigation belt was shallowly buried in the 8~10 cm surface soil at a distance of 60 cm. The drip irrigation belt was laid with 2 rows of Roman alfalfa for one pipe (Fig. 1). The specific amount of irrigation was controlled by a water meter at the intake of the plot. An internal-embedded drip irrigation belt was used (produced by Xinjiang Puxin Water Saving Co., Ltd.; the implementation standard is GB/T19812.3-2008); the working pressure was 0.1 M Pa, and the diameter was 12.5 mm. The main pipe diameter in the drip irrigation system was 90 cm, with branch pipe diameter of 75 cm, and the auxiliary pipe diameter of 32 mm. Full irrigation was carried out during the seedling stage for Roman alfalfa stand establishment, and its phenological period was recorded at the beginning of the seedling stage. In addition to water factors, other weed management practices were carried out in accordance with the local farmland practices according to the field growth.

**Experimental treatments:** Three irrigation gradients used in completely randomized block design were 6000 $m^3{\cdot}ha^{-1}$ (the irrigation amount commonly used for the local leguminous crop (*Medicago sativa* L.), conventional irrigation, $D_{100}$), 75% of the conventional irrigation amount (water deficit, 4500 $m^3{\cdot}ha^{-1}$, $D_{75}$) and 125% of the conventional irrigation amount (full irrigation, 7500 $m^3{\cdot}ha^{-1}$, $D_{125}$) with three replications. Roman alfalfa was irrigated during the growth year 8 times, with the same amount of irrigation per time, and the irrigation amounts of the $D_{75}$, $D_{100}$ and $D_{125}$ treatments were 750.0, 562.5 and 937.5 $m^3{\cdot}ha^{-1}$, respectively. Specific irrigation times were April 18, May 5, June 1, June 18, July 2, July 21, August 5, August 23, 2016; April 30, May 17, May 30, June 18, July 3, July 20, August 6, August 22, 2017; and May 5, May 20, May 31, June 20, July 20, July 28, July 18, August 7 and August 24, 2018. The temperature and rainfall of each month during the experiment (March-September 2016, March-September 2017 and March-September 2018) are shown in Fig. 2.

### Measurement index and method

**Phenophase observation:** Phenophase was observed every 2 days from the returning green stage. The specific observation methods were as follows: 30 Roman alfalfa plants were randomly selected at each time, observed at 10:00–11:00 a.m. and observed every 4 days when entering the stable growth stage. When 5~10% of plants enters a certain phenophase, it is designated as the initial stage, and when 50% of plants enter a phenophase, designated as the peak stage.

**Dry matter per plant:** In the initial flowering stage (5~10% plants in bloom), single plant of Roman alfalfa with

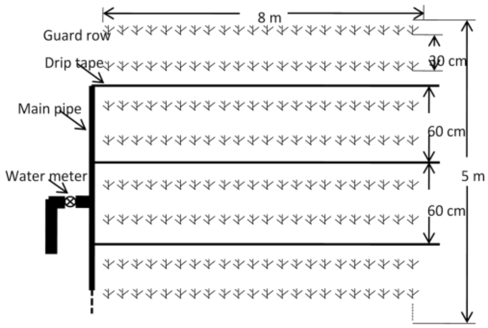


**Fig. 1:** Experiment plot of Roman alfalfa and layout of drip irrigation tape

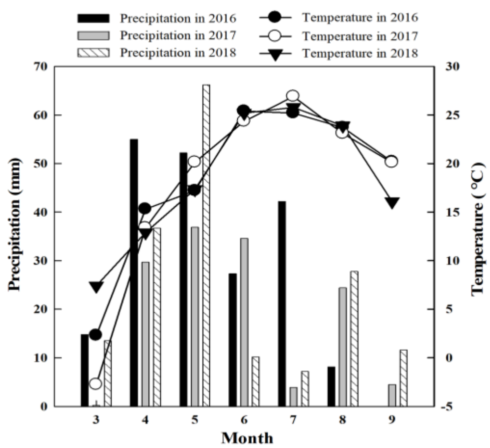


**Fig. 2:** The temperature and precipitation in growth stages during 2016–2018

uniform growth were selected using the "S" sampling method in the experimental plot. The whole plant (stubble height 5 cm) was cut with scissors and weighed after removing other weeds. The fresh weight of a single Roman alfalfa plant was recorded, and 10 repetitions were performed. Three fresh grass samples of approximately 350 g were taken back to the laboratory. After half an h of heating at 105°C in an oven and drying at 65°C for 48 h to constant weight, the moisture content of Roman alfalfa was determined, and the dry matter weight per plant (g/plant) calculated. The dry matter determination method for wild species was the same as for Roman alfalfa (Formula 1). At the same time, the hay yield of Roman alfalfa was measured by the sample method. At the beginning of Roman alfalfa flowering (5~10% of plants flowering), alfalfa plants with uniform growth were randomly selected. Using a 1 m × 1 m sample, scissors were used to cut the alfalfa plants in the sampling plot (stubble height 5 cm) and weigh them, and the fresh grass yield of Roman alfalfa plants was recorded. This process was repeated three times. According to the moisture content measured by dry matter per plant, the hay yield ($kg \cdot ha^{-1}$) of Roman alfalfa was calculated (Formula 1). The concrete formulas are as follows:

Dry matter/plant = fresh weight per plant × (1-% moisture) (1)

Hay yield = fresh grass yield × (1-moisture content) (2)

**Plant height:** At the time as of dry matter determination, 20 plants of Roman alfalfa were randomly selected for vertical height of each plant from the surface measured by steel tape, and its average value (cm) was calculated.

**Branch number:** The number of branches growing on the main stem of the selected Roman alfalfa plants was counted, that is, the number of first-order branches (individual/plant). The method for determining the number of branches for wild species was the same as that for Roman alfalfa.

**Stem-leaf ratio:** The samples of Roman alfalfa were dried to constant weight, separated from the stems and leaves and weighed, and the stem-leaf ratio was calculated (%). The method for determining the stem-leaf ratio of wild species was the same as for Roman alfalfa.

**Stem diameter:** The stem diameter (mm) at 5 cm from the ground was measured by a Vernier calliper for the 20 individual plants.

**Nutritional quality:** The crude protein (CP) content in plants was determined by the Kjeldahl method (Jackson 1967) and by multiplying the nitrogen content by 6.25 and expressed as a percentage.

Crude Protein (%) = Nitrogen (%) × 6.25 (3)

Acid detergent fibre (ADF) and neutral detergent fibre (NDF) were determined by the Soest *et al*. (1991) method.

**100-grain weight:** A total of 100 Roman alfalfa seeds of uniform size were randomly selected from the collected and dried seeds in the laboratory. The weight of the seeds was taken by electronic balance to one thousandth of a gram. The average value (g) was calculated from five repetitions.

**Germination potential and its rate:** Referring to the ISTA (1999) method, 50 seeds of Roman alfalfa of uniform size, plumpness and with no pests were randomly selected. Two filter sheets of the same size were placed in a 10 cm diameter culture dish. After wetting with distilled water, the selected Roman alfalfa seeds were added, and the process was repeated five times. The culture dish of seeds was placed in a fully intelligent artificial climate box ((25 ± 2)°C, (75 ± 5)% RH). Five millilitres of distilled water was added to each petri dish at 10:00 a.m. and 10:00 p.m. in order to keep the filter paper wet. The number of germinated seeds was recorded every day; the seeds were considered germinated when the radicle extended 1–2 mm. The germination potential (%) of Roman alfalfa seeds was calculated on the 4th day, and the germination rate (%) of Roman alfalfa seeds was calculated on the 10th day. Specific formulas are as follows:

Germination potential (%) = (Number of germinated seeds (on the 4th day) / Total number of seeds) × 100% (4)

Germination rate (%) = (Number of germinated seeds (on the $10^{th}$ day) / Total number of seeds) × 100% (5)

## Statistical analysis

Data were expressed as the mean ± standard error. Microsoft

Excel 2007 and DPS 7.05 (Data Processing System, China) were used for data processing and analysis. The Duncan method was used to analyse the significance of differences in the data. The grey correlation degree method was used to analyse the correlation between growth traits, hay yield and crude protein of Roman alfalfa under different irrigation treatments. Mapping was done in SigmaPlot 10.0.

## Results

### Phenophase of roman alfalfa

The phenophase of Roman alfalfa reflect its growth and development status. The phenophases of Roman alfalfa during 2016, 2017 and 2018 were observed. Results showed that (Table 1) the phenophase of wild Roman alfalfa was relatively stable after planting in oasis areas. The phenophases during all years were relatively close. The stages were turning green in early April, branching in late April, budding in mid-May, early flowering in early June (5–10% of plants flowering), and full flowering in late June (50% of plants blossom), which lasted for a long time (43~48 days). In early August, the alfalfa entered the podding stage (50% of plants pod), and the duration of the podding stage was relatively long (35–37 days).

### Growth characteristics of roman alfalfa under different irrigation treatments

From the sec year of growth, Roman alfalfa was irrigated for two consecutive years, and the growth traits were measured. The results showed that growth traits of Roman alfalfa showed an increasing trend with increasing irrigation, and the order of the growth traits was $D_{125}$>$D_{100}$>$D_{75}$ (Table 2). The plant height and stem diameter of Roman alfalfa were significantly different under the different irrigation treatments ($P < 0.05$), while the stem-leaf ratio and hay yield of the $D_{125}$ and $D_{100}$ treatments were significantly higher than $D_{75}$ treatment ($P < 0.05$); however, there was no significant difference between the $D_{125}$ and $D_{100}$ treatments ($P > 0.05$). The number of branches in the $D_{125}$ treatment was significantly greater than in $D_{75}$ treatment ($P < 0.05$), but there was no significant difference between the $D_{75}$ and $D_{100}$ or between the $D_{100}$ and $D_{125}$ treatments ($P > 0.05$). Conventional irrigation ($D_{100}$) and full irrigation ($D_{125}$) significantly improved the growth characteristics of Roman alfalfa.

### Nutritional quality of roman alfalfa under different irrigation treatments

The nutritional quality of Roman alfalfa under different irrigation treatments showed that crude protein (CP) content increased gradually with increasing irrigation amount, and under the $D_{125}$ and $D_{100}$ treatments were significantly higher than under the $D_{75}$ treatment ($P < 0.05$); however, there was no significant difference in CP between the $D_{125}$ and $D_{100}$ treatments ($P > 0.05$) (Table 3). Furthermore, the contents of NDF and ADF in Roman alfalfa decreased gradually with increasing irrigation amount, but there was no significant difference among treatments ($P > 0.05$). Both years showed the same pattern.

### Grey correlation analysis of growth traits, hay yield and nutritional quality of roman alfalfa under different irrigation treatments

The grey correlation analysis (Table 4) showed that the order of correlation coefficients between growth traits and hay yield was plant height > stem diameter / branch number > stem-leaf ratio, which indicated that plant height had the greatest correlation with the hay yield and had the greatest contribution to the hay yield of Roman alfalfa, followed by stem diameter/branch number and stem-leaf ratio. The order of correlation coefficients between the growth traits and CP content of Roman alfalfa was stem-leaf ratio > plant height > stem diameter > branching number over two years, which indicated that the stem-leaf ratio had the greatest correlation with the CP content and had the greatest contribution to the CP content of Roman alfalfa, followed by plant height, stem diameter and branching number.

### Comparison of growth characters in roman alfalfa in different growth years

Compared with the growth traits of Roman alfalfa under wild conditions, the plant height, branch number, stem-leaf ratio, stem diameter and dry matter of cultivated Roman alfalfa increased (Table 5) for 2016, 2017 and 2018. The plant height, branch number, stem-leaf ratio and stem diameter of Roman alfalfa in the sowing year were not significantly different from those under wild conditions ($P > 0.05$); however, the plant height, stem-leaf ratio, stem diameter and dry matter in the sec year and the third year were significantly higher than during the sowing year and under wild conditions ($P < 0.05$). The dry matter weight per plant of Roman alfalfa increased by 26.89 and 37.74% in the sec year and the third year compared with wild plants, respectively, and increased by 19.51 and 25.11% during sec and third years compared with first sowing year, respectively. There was no significant difference between the sec year and the third year ($P > 0.05$). The branching number of Roman alfalfa was significantly higher in the sec year and the third year than under wild conditions ($P < 0.05$).

### Comparison of nutritional quality of roman alfalfa in different growth years

The nutritional quality of Roman alfalfa was determined for the different growth years. The results showed that the CP content in the sec year and the third year was significantly higher than in the first year and under wild conditions ($P <$ 0.05); however, there was no significant difference in CP

**Table 1:** The phenophase of Roman alfalfa (Day/month)

| Year | Returning green stage | Branching stage | Bud stage | Early blooming stage | Full bloom stage | Fruiting period |
|---|---|---|---|---|---|---|
| 2016 | 17/4 (Sowing) | 8/5~13/5 | 14/5~1/6 | 2/6~20/6 | 21/6~8/8 | 9/8~15/9 |
| 2017 | 8/4~22/4 | 23/4~16/5 | 17/5~4/6 | 5/6~26/6 | 27/6~10/8 | 11/8~15/9 |
| 2018 | 6/4~21/4 | 22/4~14/5 | 15/5~3/6 | 4/6~24/6 | 25/6~7/8 | 8/8~14/9 |

**Table 2:** Growth traits of Roman alfalfa under different irrigation treatments

| Year | Treatment | Height (cm) | Branching number (individual/plant) | Stem-leaf ratio (%) | Stem diameter (mm) | Hay yield ($kg \cdot ha^{-1}$) |
|---|---|---|---|---|---|---|
| 2017 | $D_{75}$ | 59.7 ± 3.90c | 7.91 ± 0.35b | 1.61 ± 0.12b | 2.11 ± 0.08c | 4725 ± 161b |
| | $D_{100}$ | 72.7 ± 1.11b | 8.88 ± 0.39ab | 1.74 ± 0.21a | 2.68 ± 0.14b | 5655 ± 212a |
| | $D_{125}$ | 77.3 ± 2.43a | 10.52 ± 0.43a | 1.79 ± 0.15 a | 2.98 ± 0.12a | 6135 ± 206a |
| 2018 | $D_{75}$ | 60.1 ± 2.65c | 7.93 ± 0.38b | 1.63 ± 0.19b | 2.16 ± 0.15c | 4845 ± 189b |
| | $D_{100}$ | 72.5 ± 2.14b | 8.90 ± 0.25ab | 1.78 ± 0.14a | 2.70 ± 0.16b | 5760 ± 217a |
| | $D_{125}$ | 78.5 ± 2.33a | 10.46 ± 0.34a | 1.80 ± 0.17a | 2.92 ± 0.11a | 6015 ± 221a |

Note: Different lowercase letters in a column indicate significance ($P < 0.05$). The same below
$D_{75}$, $D_{100}$ and $D_{125}$ indicate that the irrigation amounts were 750.0, 562.5 and 937.5 $m^3 \cdot ha^{-1}$, respectively

**Table 3:** Nutritional quality of Roman alfalfa under different irrigation treatments

| Year | Treatment | Crude protein CP) (%) | Neutral detergent fibre (NDF) (%) | Acid detergent fibre (ADF)(%) |
|---|---|---|---|---|
| 2017 | $D_{75}$ | 12.16 ± 0.78b | 45.56 ± 2.12a | 23.89 ± 1.55a |
| | $D_{100}$ | 13.84 ± 0.66a | 44.38 ± 2.36a | 23.12 ± 1.43a |
| | $D_{125}$ | 13.96 ± 0.49a | 44.21 ± 2.64a | 23.04 ± 1.38a |
| 2018 | $D_{75}$ | 12.21 ± 0.52b | 45.71 ± 2.31a | 23.96 ± 1.64a |
| | $D_{100}$ | 13.86 ± 0.62a | 44.37 ± 2.58a | 23.11 ± 1.52a |
| | $D_{125}$ | 13.89 ± 0.58a | 44.25 ± 2.43a | 23.10 ± 1.41a |

Note: $D_{75}$, $D_{100}$ and $D_{125}$ indicate that the irrigation amounts were 750.0, 562.5 and 937.5 $m^3 \cdot ha^{-1}$, respectively

**Table 4:** Grey relational analysis between growth traits and hay yield of Roman alfalfa under drip irrigation

| Year | Growth trait | Correlation coefficient with hay yield | Sorting | Correlation coefficient with crude protein | Sorting |
|---|---|---|---|---|---|
| 2017 | Plant height | 0.5216 | 1 | 0.4092 | 2 |
| | Stem diameter | 0.2976 | 2 | 0.3049 | 3 |
| | Branching number | 0.2508 | 3 | 0.1442 | 4 |
| | Stem-leaf ratio | 0.2095 | 4 | 0.4624 | 1 |
| 2018 | Plant height | 0.2826 | 1 | 0.2593 | 2 |
| | Branching number | 0.2729 | 2 | 0.1430 | 4 |
| | Stem diameter | 0.2119 | 3 | 0.2188 | 3 |
| | Stem-leaf ratio | 0.1769 | 4 | 0.4554 | 1 |

Note: $D_{75}$, $D_{100}$ and $D_{125}$ indicate that the irrigation amounts were 750.0, 562.5 and 937.5 $m^3 \cdot ha^{-1}$, respectively

**Table 5:** Growth traits of Roman alfalfa in different growth years

| Treatment | Height (cm) | Branching number (individual/plant) | Stem-leaf ratio (%) | Stem diameter (mm) | Dry matter (g/plant) |
|---|---|---|---|---|---|
| Wild species | 58.40 ± 3.15b | 8.61 ± 0.53b | 1.56 ± 0.11b | 2.41 ± 0.13b | 4.16 ± 0.26c |
| The sowing year (2016) | 60.2 ± 4.05b | 8.72 ± 0.46ab | 1.59 ± 0.19b | 2.43 ± 0.11b | 4.58 ± 0.39b |
| The second year (2017) | 72.7 ± 1.11a | 8.88 ± 0.39a | 1.74 ± 0.21a | 2.68 ± 0.14a | 5.69 ± 0.31a |
| The third year (2018) | 72.5 ± 2.14a | 8.90 ± 0.25a | 1.78 ± 0.14a | 2.70 ± 0.16a | 5.73 ± 0.34a |

between the sec year and the third year ($P > 0.05$). With the increase in growth years, the contents of NDF and ADF decreased slightly, but there was no significant difference between different years ($P > 0.05$). The effect of growth year on the improvement of nutritional quality of Roman alfalfa was not obvious.

### Seed characteristics in different growth years of roman alfalfa

The 100-grain weight of wild Roman alfalfa was significantly higher than first generation ($P < 0.05$), and of the wild alfalfa reached 0.1386 g (Table 7). With the increase in growth years, the 100-grain weight of Roman alfalfa in the first generation decreased gradually, but there was no significant difference between years ($P > 0.05$). The germination potential and germination rate of wild species were significantly higher than the first generation ($P < 0.05$), and those of the first generation decreased to their lowest level in the third year.

## Discussion

Irrigation is a very important cultivation measure in alfalfa

**Table 6:** Nutritional quality of Roman alfalfa in different growth years (%)

| Treatment | Crude protein (CP) | Neutral detergent fibre (NDF) | Acid detergent fibre (ADF) |
|---|---|---|---|
| Wild species | 13.17 ± 0.54b | 45.31 ± 2.87a | 23.63 ± 1.35a |
| The sowing year (2016) | 13.26 ± 0.79b | 44.42 ± 2.45a | 23.15 ± 1.84a |
| The second year (2017) | 13.84 ± 0.66a | 44.38 ± 2.36a | 23.12 ± 1.43a |
| The third year (2018) | 13.86 ± 0.62a | 44.37 ± 2.58a | 23.11 ± 1.52a |

**Table 7:** Seed properties of Roman alfalfa under different growth years

| Growth year | Hundred grain weight (g) | Germination potential (%) | Germination rate (%) |
|---|---|---|---|
| Wild species | 0.1386 ± 0.0009a | 7.13 ± 0.31a | 9.21 ± 0.38a |
| The sowing year in $F_1$ (2016) | 0.1074 ± 0.0006b | 3.56 ± 0.16b | 5.64 ± 0.22b |
| The second year in $F_1$ (2017) | 0.1069 ± 0.0008b | 3.32 ± 0.14b | 5.56 ± 0.28b |
| The third year in $F_1$ (2018) | 0.0967 ± 0.0007b | 0 ± 0c | 1.02 ± 0.13c |

production, and it has an important impact on the growth characteristics and hay yield of alfalfa. Studies have shown that drip irrigation can increase alfalfa hay yield, reduce the amount of water used and reduce agricultural production costs (Ayarsa *et al*. 2015). Through the study of alfalfa under drip irrigation in the Xinjiang oasis region, it was found that the plant height, leaf-stem ratio, stem diameter, growth rate and hay yield of alfalfa increased gradually with increasing irrigation amount (Zhang *et al*. 2016). This study shows that with increasing irrigation amount, the growth traits of Roman alfalfa increased gradually. Although the plant height and stem diameter of Roman alfalfa were significantly different among the irrigation treatments and the stem-leaf ratio, branch number and hay yield of the $D_{125}$ treatment were significantly higher than $D_{75}$ treatment, there was no significant difference between the $D_{125}$ and $D_{100}$ treatments (Table 2), indicating that the increase in irrigation amount improved the growth characteristics of Roman alfalfa, but the effect of excessive irrigation was not obvious.

Growth traits had an important impact on alfalfa yield and can be used as an index of hay yield and nutritional quality (Montazar and Sadeghi 2008). The results showed that the correlation between plant height, growth rate and hay yield was extremely significant, and the contribution rate of plant height and branch number to alfalfa yield was positive (Wang 2007; Zhang *et al.* 2017). At the same time, plant height can be used as an important index of hay yield and nutritional quality of alfalfa (Cacan *et al.* 2018). This study shows that the correlation between plant height and hay yield was the greatest, and the correlation between plant height and CP content was sec to stem-leaf ratio and CP content (Table 4), indicating that plant height and stem-leaf ratio could be used as indicators of the growth traits and nutritional quality of Roman alfalfa. This may be due to the relatively small leaves and strong stems of Roman alfalfa (Cui 1992), which result in a relatively high stem-leaf ratio. Therefore, the hay yield and nutrient quality of Roman alfalfa changed significantly with the change in plant height and the stem-leaf ratio.

At the same time, this study showed that the dry matter weight per plant of Roman alfalfa in the sec year was 26.89% higher than under wild and normal irrigation conditions (Table 5), and the yield significantly increased. One possible reason was that, unlike the wild conditions, this study was conducted under drip irrigation conditions. Drip irrigation systems lie in moist soil close to the plants; the root system is concentrated in the area with soil moisture and in a suitably humid environment, conducive to root respiration, and with the high drip irrigation frequency. Thus, the root systems of crops in arid areas were kept at a suitable humidity for a long time, the root respiration and contribution rate of root respiration were all increased, and the crop yield was increased (Zhang *et al.* 2013). The research on alfalfa showed that under constant irrigation amount conditions, applying 35% of the total irrigation amount before cutting and 65% of the total irrigation amount after cutting could increase the plant height and hay yield of alfalfa (Zhang *et al.* 2017), which indicated that reasonable irrigation amounts and irrigation quota distribution could significantly increase the hay yield of alfalfa. This study showed that compared with the water deficit treatment, normal irrigation significantly increased the hay yield of Roman alfalfa (Table 2). Therefore, combined with a suitable irrigation amount and a suitable irrigation quota allocation system, Roman alfalfa has good yield potential and can be used as a high-quality forage in the Xinjiang oasis area.

Appropriate irrigation can significantly improve the nutritional quality of alfalfa. Results showed that the stem-leaf ratio of alfalfa decreases and the crude protein content increases under subsurface drip irrigation, which improves the quality of alfalfa. However, with water deficit irrigation, the yield of alfalfa decreases dramatically, and the total crude protein yield eventually decreases (Kou *et al*. 2014). This study showed that with the increase in the irrigation amount, the CP content of Roman alfalfa increased gradually, and in the $D_{125}$ and $D_{100}$ treatments was significantly higher than in the $D_{75}$ treatment, but there was no significant difference in CP between the $D_{125}$ and $D_{100}$ treatments (Table 3). This indicated that irrigation could increase the CP content of Roman alfalfa in a certain range of irrigation amounts, mainly because Roman alfalfa is a water-loving crop. Xinjiang is a typical continental arid climate in which evaporation is intense, soil water loss is fast, and much water is needed to meet the growth and development needs of the plant, so the CP content of Roman alfalfa increases with the increase in irrigation. The results showed that the contents of NDF and ADF in Roman alfalfa decreased gradually with increasing irrigation amount, but there was no significant difference among the treatments (Table 3). This indicated that the irrigation amount could reduce the NDF and ADF contents of Roman alfalfa appropriately, but the improvement effect was not great. This may be because the stem of Roman alfalfa is strong, and the effect of irrigation amount on the stem-leaf ratio was small (Table 2), which leads to lower influence of irrigation on the contents of NDF and ADF.

Growth years had a certain influence on the growth characteristics of alfalfa. A study showed that the hay yield of alfalfa in the fifth year was significantly higher than in the sowing year (Fan *et al*. 2016). From the sixth year, the hay yield of alfalfa significantly decreased (Gu *et al.* 2018). The plant height, branch number, and stem-leaf ratio in the sowing year of Roman alfalfa were not significantly different than in wild conditions, but the plant height, stem-leaf ratio and dry matter of Roman alfalfa in the sec year were significantly higher than in sowing year and in wild conditions (Table 5). The effect of growth year on the nutritional quality of Roman alfalfa was not obvious; only the CP content in the sec year was significantly higher than in sowing year and in wild conditions. The NDF and ADF contents were not affected by different years (Table 6), which indicated that there was a certain adaptation period for Roman alfalfa from its wild state to the oasis area and there would be better performance after the adaptation period. This may be because the Roman alfalfa is the same variety and its natural characteristics will not change over a few years, so there was no significant change in the nutritional quality of Roman alfalfa between years (Table 6), but irrigation had a certain impact on the increase in the CP content (Table 2). It can be seen that irrigation can improve the CP content of alfalfa. At the same time, the results of this study provided experimental data for only three years. Whether the nutritional quality of Roman alfalfa will change over a longer period of time still needs further study.

Growth year had a certain influence on the seed characteristics of alfalfa. The results showed that the 1000-grain weight of *Vicia tenuifolia* seeds decreased with the extension of domestication time (Zhang *et al*. 2013). This study showed that the 100-seed weight, germination potential and germination rate of Roman alfalfa under wild conditions were all greater than the first generation (Table 7). This is mainly because in the long-term natural selection process, plants in harsh environments have a complete set of conservation mechanisms to continue their germplasm (Han 1997). However, the 100-grain weight, germination potential and germination rate of Roman alfalfa decreased gradually over the growing years (Table 7). This may be due to the different climate in the growing fields of Roman alfalfa, which results in domesticated seeds becoming smaller and drier (Lin 2008). Meanwhile, the germination potential and rate of the first generation of Roman alfalfa decreased significantly in the third year of growth (Table 7). This may be related to the hard seed rate of Roman alfalfa seeds, but the specific mechanism of its impact still needs further study.

## Conclusion

Appropriate irrigation (6000 $m^3 \cdot ha^{-1}$) significantly improved the growth traits and nutritional quality of Roman alfalfa, and it significantly increased the CP content; however, it had no significant effect on contents of NDF and ADF. The contribution rates of plant height to the hay yield and of stem-leaf ratio to CP content were the largest for Roman alfalfa and could be used as indicators of growth traits and nutritional quality. Growth year had no significant effect on growth traits or NDF and ADF of Roman alfalfa. The 100-grain weight under wild conditions was significantly higher than the cultivated alfalfa. Therefore, under appropriate irrigation conditions, Roman alfalfa can be cultivated and domesticated as a high-quality leguminous forage in the oasis region.

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